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A SUMMARY OF FOUR YEARS' EXPLORATORY STUDY OF MOUNTAIN PINE BEETLE INFESTATIONS IN WESTERN WHITE PINE

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A SUMMARY OF FOUR YEARS' EXPLORATORY STUDY OF MOUNTAIN PINE BEETLE INFESTATIONS IN WESTERN WHITE PINE

(h-1-1-10)

The objective of this study is to answer two questions: (1) How do mountain pine beetle infestations in western white pine behave and what causes this behavior? (2) On what basis can the future trend of these infestations be predicted? The answers to these questions have an immediate application in selecting areas in need of control as well as in the actual administration of control work.

The present report summarizes the results of four seasons' exploratory work on this study accomplished during 1936 to 1939 inclusive.

METHODS

The first problem in this study was to develop a satisfactory method of sampling, that is, to determine the minimum amount of bark which must be sampled to give an accurate population of the various insects beneath the bark of each tree. Earlier workers 1,2,3/ in

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1/ De Gryse, J. J. Quantitative methods in the study of forest insects. Sci. Agr. 14:9:477-495. 1934.

2/ Gobeil, A. R. Population study of Ips perturbatus Eichh. Ann. Rept. Ent. Soc. Ont. 1935.

3/ Tragardh, Ivar. A new method of obtaining an accurate estimate of the number of insects infesting storm-ravaged forests. Proc. 5 Pac. Sci. Congr. Cana. 1933.

and Butovitsch, Viktor. Some forest entomological methods and conceptions. Bull. Ent. Res. 29:2. 1938.

bark beetle population studies had developed methods, but these were mainly suited for use in their own particular problems.

The first step in the white pine study therefore was to ascertain the minimum sample per tree which was in keeping with the accuracy desired. This was done by varying the amount of bark sampled on each of ten trees until all of the infested bark had been removed and examined. It was found that four one-half-square-foot bark samples, one each located on the north, east, south and west sides of the tree and spaced at distances of 5, 20, 40, 60, 80, etc., feet along the felled tree, measuring from its root collar, gave results which in no case were more than 10 percent in error when compared with the results of examining all of the infested bark.

Owing to the long length of bole of this tree species infested by the mountain pine beetle, there is a wide range in population density from the base to the top of the tree. There is also a considerable taper in the tree bole along this length. Thus it is incorrect to use a mean population figure per square foot determined by averaging all of the samples, because the taper of the tree results in the upper samples representing a lesser bark surface than those at the base of the tree, so that a simple arithmetic average causes an unequal representation of the population variation. Therefore, the data from each set of four samples were weighted by the number of square feet of bark represented by the samples in order to secure the mean for the tree. As stated, this resulted in no error greater than 10 percent.

Using this technique, infested trees of two types were sampled during each season. Trees of the previous season's attack were sampled to secure final emergence figures and trees containing various stages of brood development attacked during the current season were examined to secure average brood mortality. Only final emergence data are used in this report.

The sampling work was done by CCC enrollees under the direct supervision of an experienced foreman or one of the laboratory permanent personnel. In this connection, Mr. T. T. Terrell of the Coeur d'Alene Laboratory spent considerable time during the first three seasons in directing and supervising the crew and also aided materially in planning the work. In analysing the data for this report, Mr. F. P. Keen of the Portland Laboratory donated generously of his time to direct and supervise the statistical work and to review the manuscript.

SUMMARY OF ELIMINATED FACTORS

Of necessity, this study was based on an elimination procedure. At the outset, all possible measurable factors thought to influence mountain pine beetle abundance were included. As the work progressed, certain of these factors were obviously of no significance and were eliminated to permit greater concentration on the more important ones.

The first variable eliminated was period of attack. The data from two seasons' work, when tabulated according to whether the trees were attacked during the early, midseason, or late attack period showed no significant differences in brood abundance between periods of attack.

Exposure showed no effect on brood abundance in western white pine only in so far as it was influenced by site moisture. Similarly, site quality based on age and height of the stand was found to be a poor index of present site conditions, although in general the site moisture classes compared favorably with the site quality classes, the dry sites being grouped in sites IV and V and wet sites being mostly in I and II.

The location of the infestation according to areas was found to show truly significant differences between areas. Because of this, the study was restricted to one area in order to eliminate this variable.

The number of eggs laid per attack was found to be surprisingly constant throughout the years of the study. Each female beetle lays approximately 50 eggs per gallery, the greatest number per inch being deposited in the fifth and sixth inches and practically the entire number before the fourteenth inch of gallery has been completed. This holds true regardless of the length of the gallery. This would have introduced an important variable into the study had any great variation been found.

The factor of parent adult emergence and reattack was thought to have a pronounced influence, not on the brood produced in individual trees but on the number of trees infested in any given area. It was found however that parent emergence appears to be a normal habit of the mountain pine beetle and is not influenced by any of the factors measured in this study such as bark thickness, exposure, crowding or

height on the tree. The amount of parent emergence per tree depends entirely on the number of beetles which made their first attack in it, as only two attacks are made by each female. Parent emergence was therefore eliminated from further consideration in this study.

EFFECT OF VARIOUS FACTORS ON MOUNTAIN PINE BEETLE ABUNDANCE

There remain eight other factors which were thought to have some influence on mountain pine beetle abundance. These are year of attack, site moisture, tree diameter, bark thickness, volume of egg gallery, density of attack, abundance of beneficial insects and types of host material. Each of these is discussed in the order named.

Seasonal Influence

Variations in the infestation from year to year are quite marked even to casual observation. It is of course the object of this study to determine and evaluate the causes for tnese seasonal fluctuations. Nevertheless, the influence of year of attack is compounded in the study and must be considered throughout as another variable.

Table 1 shows the effect of year of attack on the different biological factors included in the study.

Table 1 - Status of infestation during four years of study

Year of att.	Trees examined	Inf. bark per tree	Average per square foot: D.m. brood	Attacks	Parent emerg. holes	Egg gallery	Para-sites	Preda-tors	Robber work a/
	no.	sq.ft.	no.	no.	no.	inches	no.	no.	sq.in.
1935	133	190**	7.7**	8.5*	5.7**	100.4**	4.7**	2.4**	14.3**
1936	106	191**	38.3**	3.3**	1.9**	54.3**	3.6*	1.4	23.1*
1937	56	270**	24.0**	3.5**	3.7	75.7	1.7**	0.8*	26.9
1938	109	324**	15.5**	9.7**	3.9	75.7	1.5**	0.6**	42.5**
Mean	404	238	19.5	7.0	3.9	77.7	2.8	1.2	28.5

a/ Robber work includes woodpecker work, secondary work and wood borer work.

** Difference from mean highly significant.

* Difference from mean significant.

No asterisk indicates no significant difference.

As shown in table 1, most of the yearly means are significantly different from the four-year mean, showing that there are true differences in an infestation during different years. Some exceptions are to be noted where the yearly means are very close to the four-year mean. However, none of factors shown in the table give any satisfactory indication as to why there is this seasonal fluctuation in mountain pine beetle population. Further consideration will be given this subject after the other factors have been discussed.

Site Moisture

For the purpose of this study, the various white pine sites were divided into wet, moist or dry according to the apparent moisture of

the area, which was determined by vegetation, location of the tree in relation to water, and general appearance of the site. The wet sites are close to water either in bottomland, lower slopes of ridges or in the bottoms of small side draws. They are characterized by a luxuriant growth of ground cover comprising devil's club, ferns and gooseberry. The moist sites are farther removed from water about midway up the ridge as indicated by the presence of goat brush, thimbleberry, rose, black currant, and honeysuckle. The dry sites are found in openings and on the higher slopes and ridge tops where huckleberry, Rocky Mountain maple, Douglas fir, bear grass, sticky laurel and nine bark are the main indicator plants.

The effect of site moisture on the population of the insects studied is shown in table 2.

Table 2 - Effect of site moisture on insect population in western white pine.

Site Moisture	Trees examined	Infested bark per tree	D.m. brood	Attacks	Parasites	Predators	Robber work
	no.	sq.ft.	no.	no.	no.	no.	sq.in.
Wet	118	278**	28.0**	8.5**	3.6	1.7*	30.6
Moist	118	262*	17.0	7.8	2.5	1.1	28.3
Dry	168	191**	8.5**	4.9**	2.3	0.8	26.9
Mean	404	238	19.5	7.0	2.8	1.2	28.5

** Difference from mean highly significant.

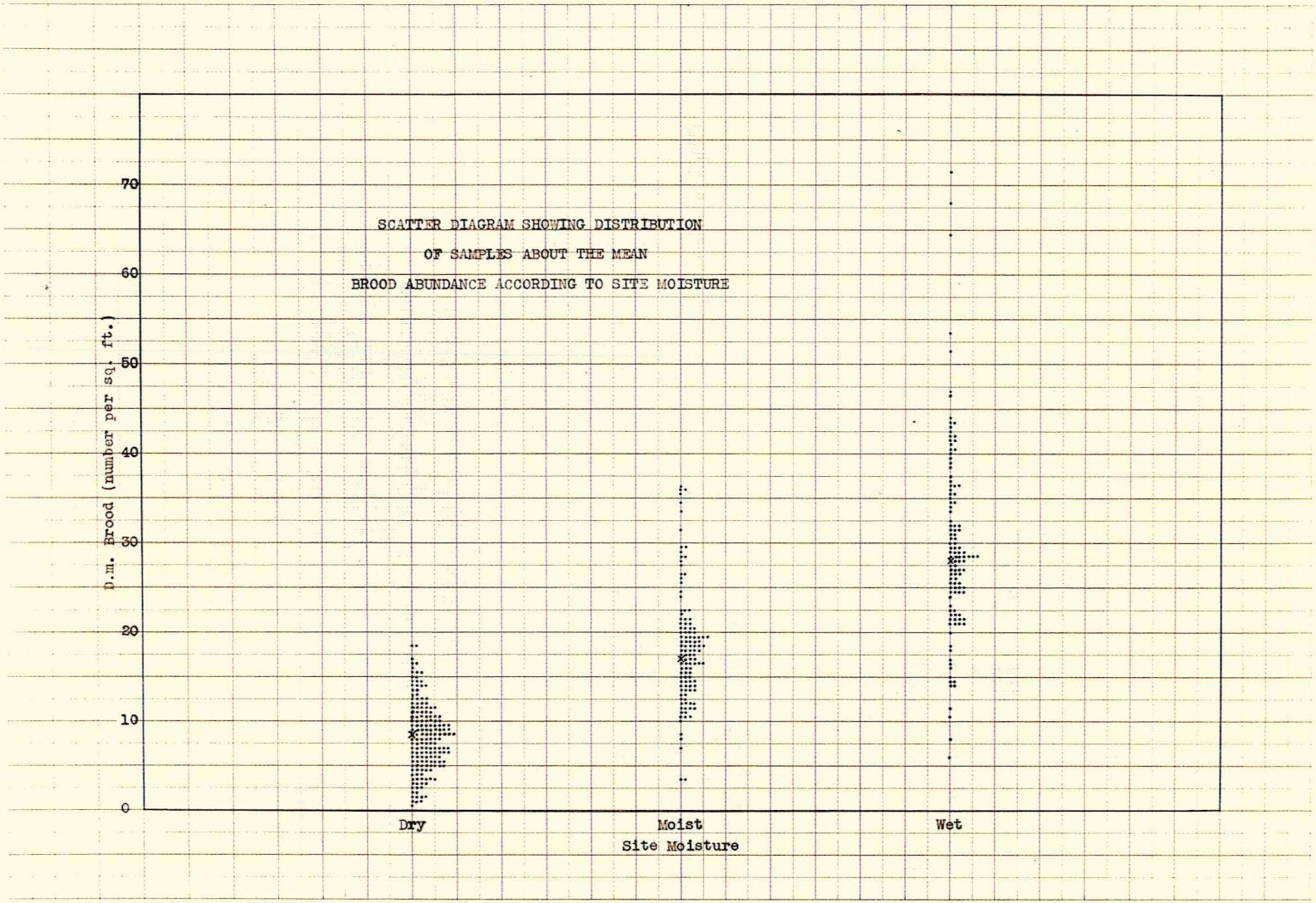
* Difference from mean significant.

No asterisk indicated no significant difference.

It is readily apparent in this table that site moisture exerts a pronounced influence on mountain pine beetle population. Moist sites represent conditions very close to the mean infestation, while wet sites offer optimum conditions and dry sites show the lowest D.m. population. Beneficial insects, excepting predators in wet-site trees, show no significant differences from the mean, which is also true of robber work. Both attacks and brood differ significantly.

The relationship between D.m. brood and site moisture is further emphasized by the scatter diagram shown in plate I, which shows that the samples are well grouped about the means . It may therefore be concluded that site moisture influences tree condition to such an extent that its effect is felt in D.m. populations in spite of the effect of other influential variables.

Plate I


SCATTER DIAGRAM SHOWING DISTRIBUTION
OF SAMPLES ABOUT THE MEAN
BROOD ABUNDANCE ACCORDING TO SITE MOISTURE
D.m. Brood (number per sq. ft.)
70
60
50
40
30
20
10
0
Dry
Moist
Wet
Site Moisture

Tree Diameter

It is obvious that the larger-diameter trees provide a greater bark surface for insect attack and are thus capable of producing a greater number of beetles. However, there is no basis to assume that these larger trees contain a greater D.m. population per square foot of infested bark. Table 4 shows the status of the infestation in trees of various diameters.

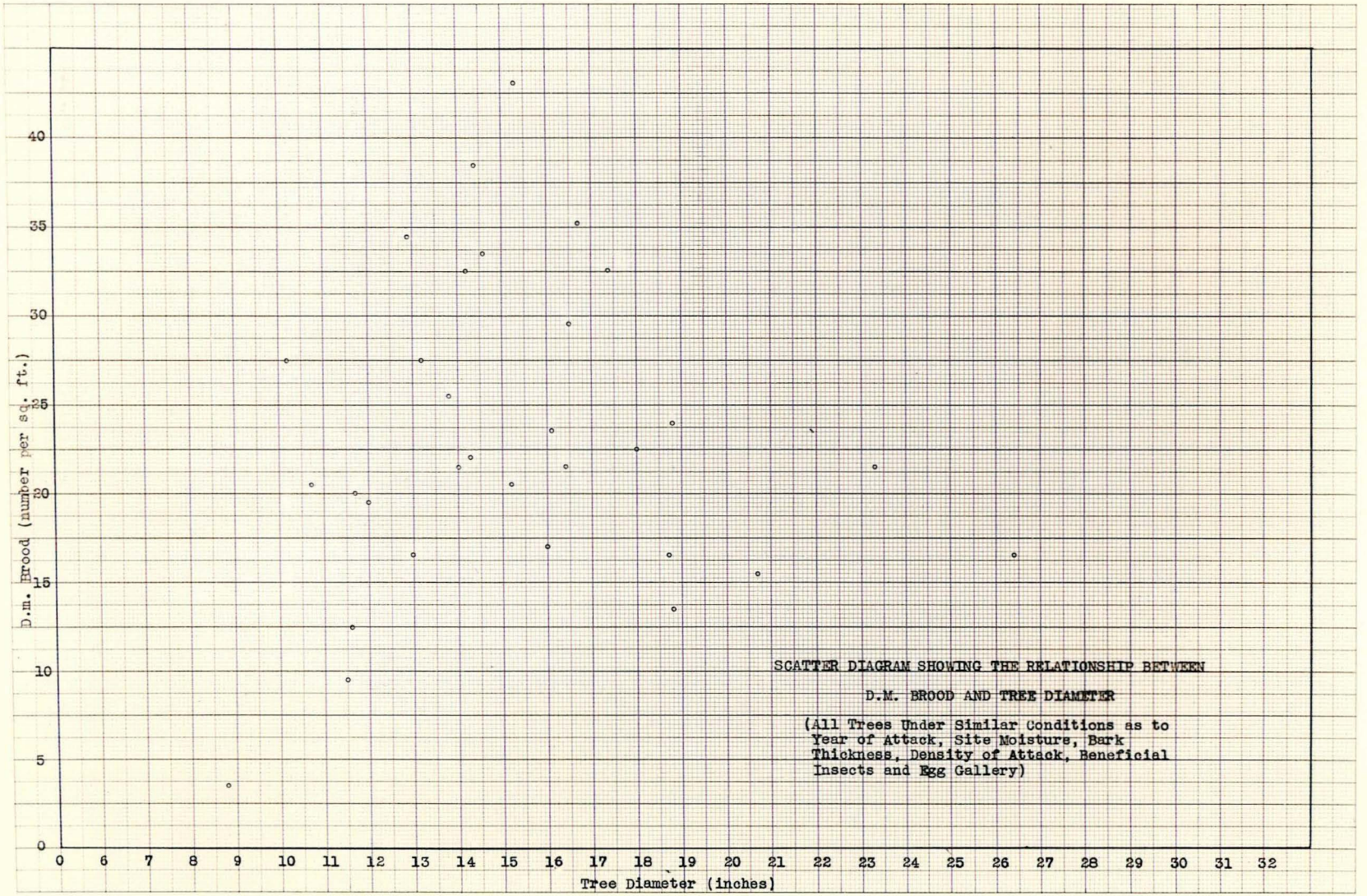
Table 4 - Effect of tree diameter on insect population.

D.b.h.	Trees sampled	Average per square foot				
		D.m. brood	Attacks	Egg gallery	Parasites	Predators
inches	no.	no.	no.	inches	no.	no.
6-10	37	3.9	5.6	56.6	3.9	0.4
11-12	55	13.8	5.4	59.7	7.0	0.8
13-18	166	16.8	6.6	75.8	3.4	1.0
19-24	106	20.4	7.6	82.3	2.2	1.3
25 +	40	25.4	7.4	85.6	0.7	1.8

The trend D.m. brood in table 4 is toward a greater population in the larger-diameter trees. This must be tempered however by the fact that both number of attacks and inches of egg gallery increase with increasing diameter. In addition, year of attack and site moisture are not given consideration in this table.

The scatter diagram shown in plate II expresses this relationship much more accurately when the comparison is between trees under similar conditions as to year of attack, site moisture, bark thickness, density of attack, beneficial insects and egg gallery. In this diagram

Plate II



SCATTER DIAGRAM SHOWING THE RELATIONSHIP BETWEEN

D.M. BROOD AND TREE DIAMETER

(All Trees Under Similar Conditions as to Year of Attack, Site Moisture, Bark Thickness, Density of Attack, Beneficial Insects and Egg Gallery)

a curvilinear regression is indicated, with maximum broods being produced in the average-sized trees and less abundant broods in both the smaller and larger trees. The explanation for this relationship will be brought out in the next section dealing with bark thickness.

Bark Thickness

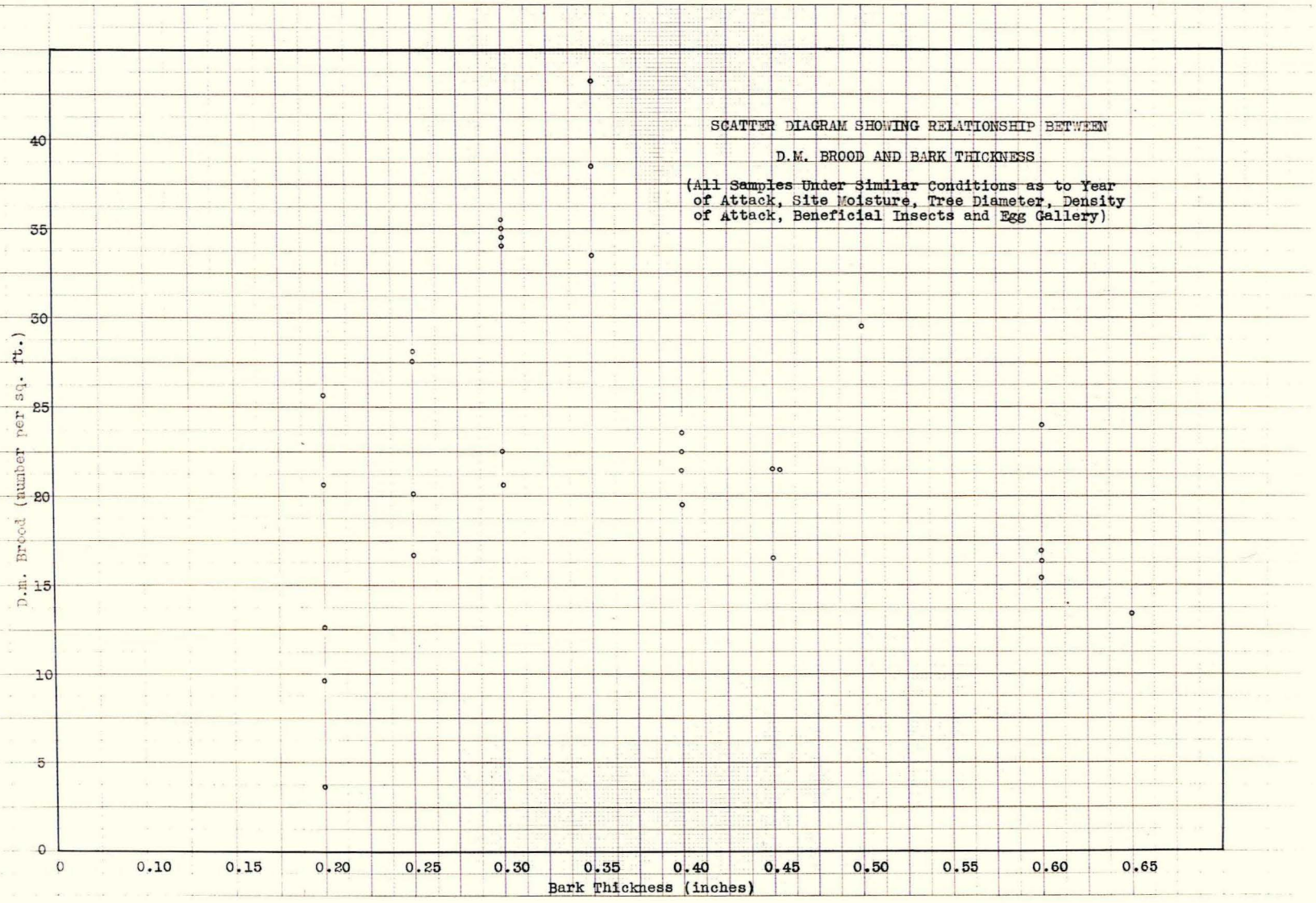
The importance of bark thickness has already been indicated in discussing tree diameter. Table 5 shows the abundance of D.m. brood and beneficial insects under various conditions of bark thickness.

Table 5 - Effect of bark thickness on insect population

Bark thickness	Samples	Average per square foot			
		D.m. brood	Attacks	Parasites	Predators
inches	no.	no.	no.	no.	no.
0.1	185	11.0	3.6	4.1	0.4
0.2	416	22.8	5.9	4.0	0.9
0.3	246	31.5	6.5	2.6	0.9
0.4	242	19.7	7.7	2.1	1.0
0.5	142	20.4	9.2	2.0	1.5
0.6 +	116	17.4	12.5	2.8	4.5

This table shows what appears to be an optimum bark thickness of 0.3 inch for mountain pine beetle development. This curvilinear relationship is also apparent in the scatter diagram shown in plate III, in which bark thickness and D.m. brood are the main variables, all samples being under similar conditions regarding the other factors.

Plate III


SCATTER DIAGRAM SHOWING RELATIONSHIP BETWEEN
D.M. BROOD AND BARK THICKNESS
(All Samples Under Similar Conditions as to Year of Attack, Site Moisture, Tree Diameter, Density of Attack, Beneficial Insects and Egg Gallery)
D.M. Brood (number per sq. ft.)
0
5
10
15
20
25
30
35
40
0
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
Bark Thickness (inches)

It is easily understood that the medium-diameter trees contain more bark of medium thickness which is optimum for D.m. development and thus the medium diameter trees contain the greatest D.m. population. However, it is not so easy to explain why D.m. broods develop more abundantly in bark 0.35 inch thick. It is seen in table 5 that beneficial insects tend to be least numerous where most abundant D.m. broods occur. This, however, is not an entirely satisfactory explanation both because of the low beneficial population as well as the type of relationship between D.m. brood and beneficial which will be shown later.

Moisture control beneath the bark is probably a much more logical hypothesis, although no data are available to form any basis for this assumption. It is known that thick bark is wetter and thin bark drier than medium thick bark and it is therefore possible that the medium bark offers optimum moisture conditions for D.m. development.

Egg Gallery

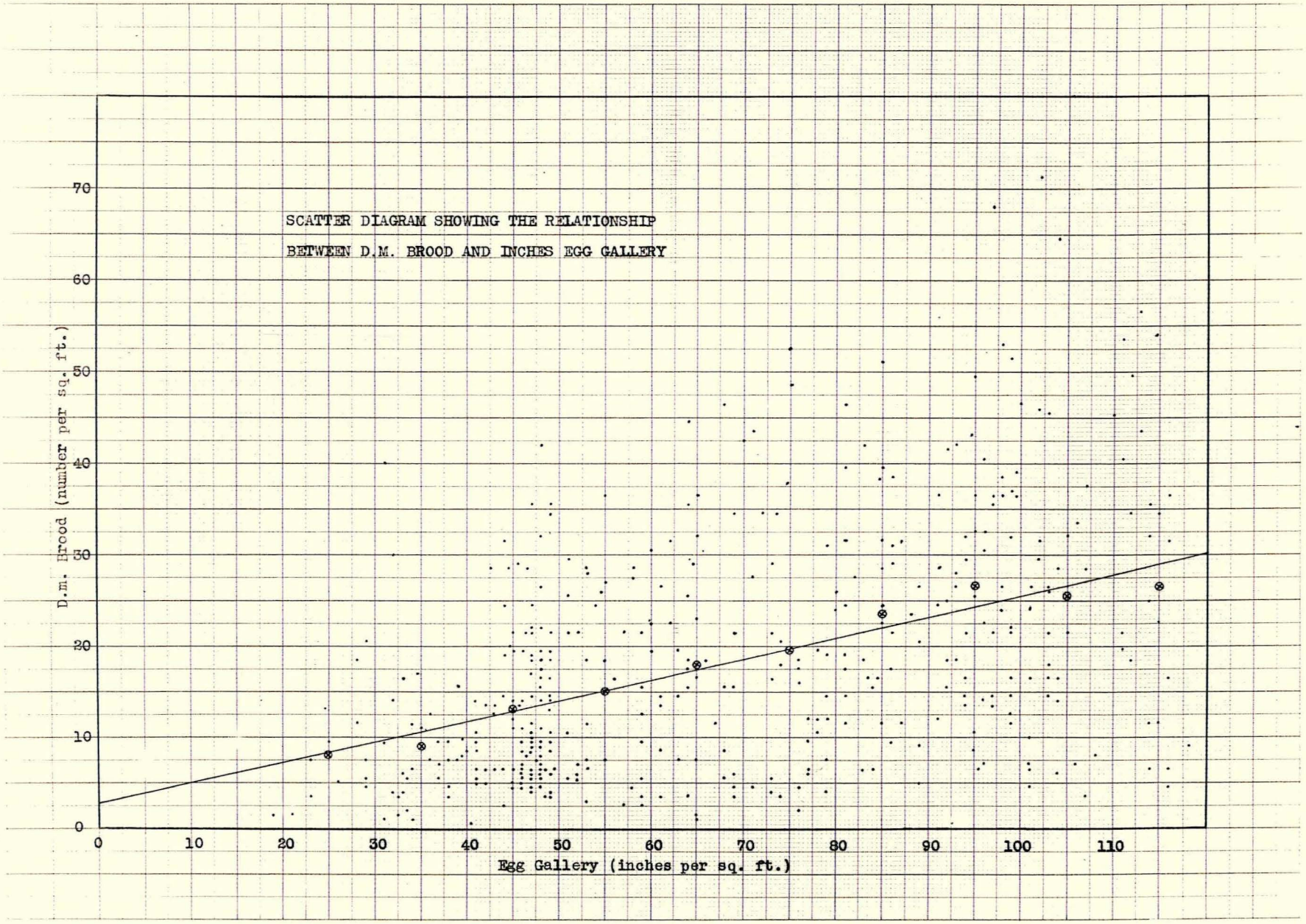
It is to be noted in tables 1 and 4 that there is an apparent straight line relationship between the lineal inches of egg gallery and the amount of D.m. brood. Table 6 shows D.m. population according to the amount of egg gallery for each of the four years as well as the mean of these years.

Table 6 - Effect of inches of gallery on D.m. population

Year	Lineal inches egg gallery per square foot											
	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	131-140	181-190
	D.m. brood per square foot											
1935	6.4	7.0	7.8	7.9	10.0	9.7	16.5	14.4	12.3	11.5		5.8
1936	16.8	12.3	18.9	23.4	30.4	33.3	36.5	37.0	42.3	49.1		
1937	1.7	7.5	14.9	11.2	17.0	29.6	21.5	34.2	30.5	48.3		
1938	5.0	8.5	11.1	9.3	12.6	8.4	24.0	30.6	31.5	33.3	15.2	
Mean	8.0	9.1	13.3	15.3	18.1	19.4	23.4	26.9	25.2	26.9	15.2	5.8

Although some irregularities are apparent in individual years, the mean of the four years shows a progressive increase in D.m. population, as the amount of egg gallery increases with a maximum production at 91 to 120 inches. The last two items indicate a drop in population beyond this point, but these entries are represented by only five samples so that their value is somewhat doubtful. It is logical to assume however that this would be a curvilinear relationship because there must be a point where an increase in egg gallery would cause overcrowding and result in some mortality of D.m. brood.

Without a sufficient representation in these higher groups, however, the last two items were eliminated and the regression equation computed using the average points on the basis of a straight line regression. The equation was found to be $\bar{x} = .228y + 2.600$, which places the regression line as shown on the scatter diagram in plate IV. It is to be noted, however, that there is a wide dispersion of points making up these averages.


SCATTER DIAGRAM SHOWING THE RELATIONSHIP
BETWEEN D.M. BROOD AND INCHES EGG GALLERY
D.m. Brood (number per sq. ft.)
0
10
20
30
40
50
60
70
0
10
20
30
40
50
60
70
80
90
100
110
Egg Gallery (inches per sq. ft.)

Density of Attack

Closely associated with the amount of egg gallery is the density with which the tree is attacked. It is apparent that the more numerous the attacks, the more abundant will be the amount of egg gallery. Table 7 shows this relationship as well as that between D.m. brood and density of attack.

Table 7 - Effect of density of attack on D.m. brood and associated factors

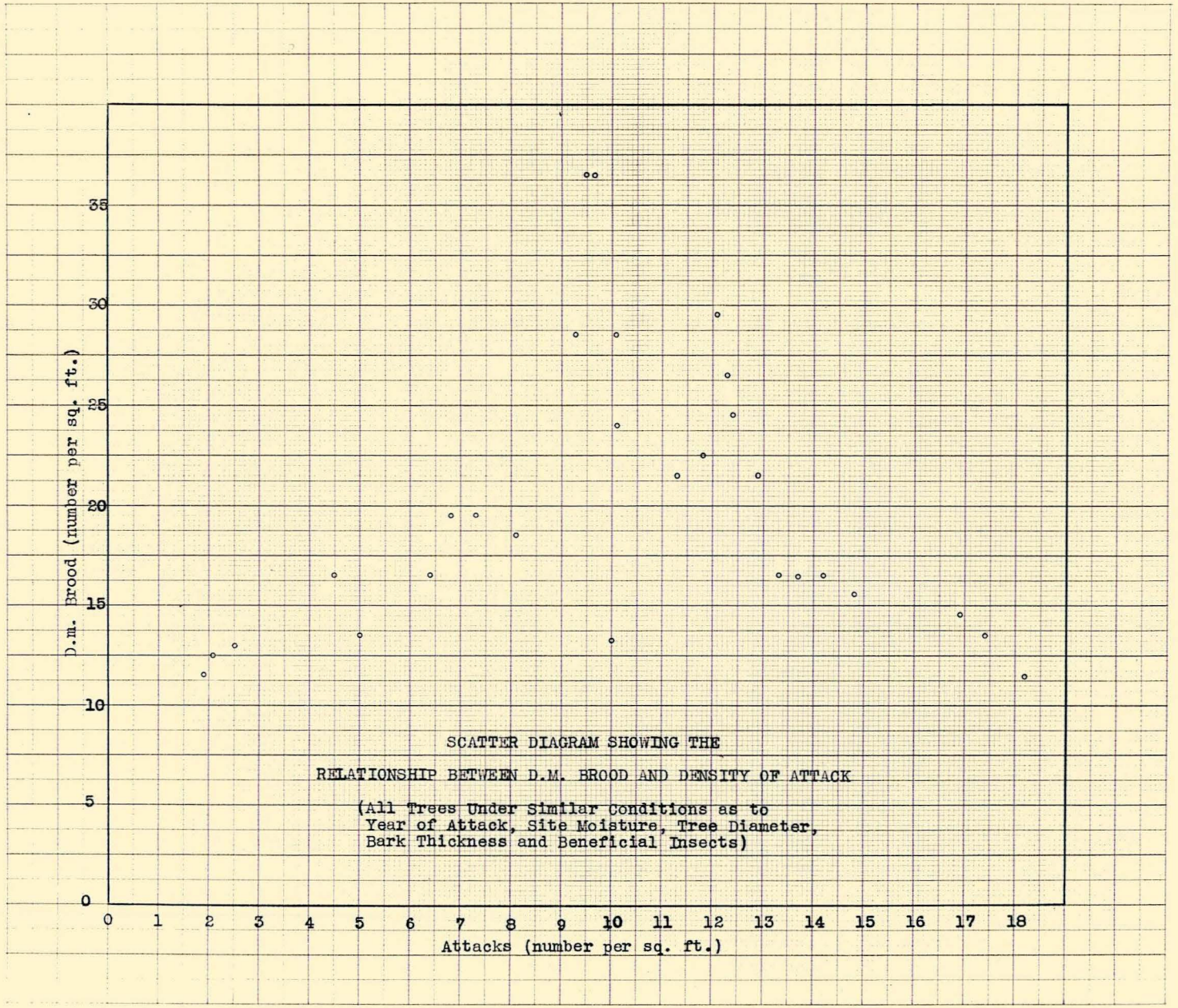
Attacks per square foot	Trees sampled	Average per square foot: D.m. brood	Egg gallery	Parasites	Predators	Total bark destroyed a/
no.	no.	no.	inches	no.	no.	sq.in.
1-2	108	10.2	35.4	3.4	1.0	47.5
3-4	69	17.4	66.0	4.1	1.0	41.1
5-6	56	21.6	68.0	2.3	1.2	39.7
7-8	56	38.8	94.0	2.4	1.9	47.4
9-10	60	76.4	112.9	2.0	3.4	49.3
11-12	33	12.3	111.7	1.9	2.1	46.4
13-14	11	16.4	123.4	1.9	2.2	38.1
15-18	9	23.9	138.9	1.6	0.7	42.4
28&36	2	4.7	149.4	1.7	0.3	33.8

a/ Total bark destroyed represents the work of secondary bark beetles, wood borers and woodpeckers, plus the volume of D.m. egg gallery.

Some slight discrepancies will be noted between tables 6 and 7, accounted for by the fact that one was prepared on a tree basis while

the other is on a sample basis. However, table 7 shows what appears to be another curvilinear relationship between brood and attacks. The amount of bark destroyed in gallery construction and by other agencies does not appear to be effective in this relationship, nor does the population of beneficial insects.

Plate V is a scatter diagram showing the relationship between D.m. brood and density of attack when all trees are under similar conditions as to year of attack, site moisture, tree diameter, bark thickness and beneficial insects. This diagram indicates that most abundant broods result from 9 to 13 attacks per square foot. This coincides closely with expectations on the basis of brood potential, because attacks in this density result in egg galleries averaging approximately 12 inches long and since most all eggs are deposited before the fourteenth inch of gallery, attacks in this density would provide a maximum brood potential. This would indicate that where attacks are of such numbers as to produce the maximum number of eggs with a minimum amount of egg gallery, the maximum number of individuals will reach maturity. In a simple correlation between D.m. brood and density of attack, the correlation coefficient was found to be only +.08, which would indicate no significant relationship between the two. Probably one reason why this correlation failed to show significance is the apparent curvilinear relationship between these factors as shown in Plate V.



SCATTER DIAGRAM SHOWING THE

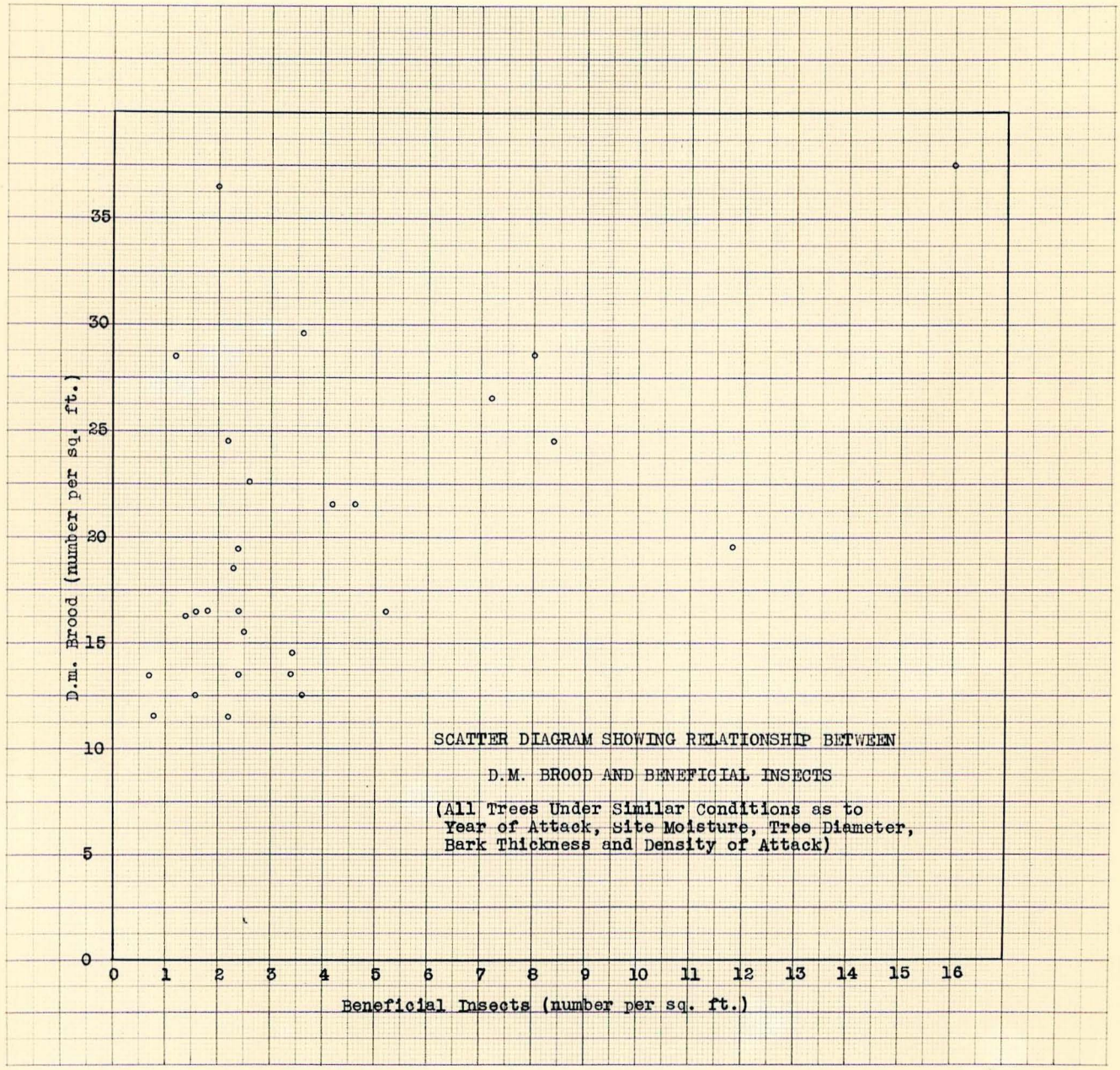
RELATIONSHIP BETWEEN D.M. BROOD AND DENSITY OF ATTACK

(All Trees Under Similar Conditions as to
Year of Attack, Site Moisture, Tree Diameter,
Bark Thickness and Beneficial Insects)

Beneficial Insects

Parasites and predators undoubtedly have some effect on D.m. populations, but the statistical data on this point failed to show any significant relationship. A simple correlation showed a correlation coefficient of +.50 indicating a very slight relationship between the two, but the tendency was for beneficials to increase with increasing D.m. populations. This is further indicated in the scatter diagram represented by plate VI. Therefore, since greater beneficial insect populations appear to be associated with more abundant D.m. broods, the exact effect of beneficial insects can not be determined from this study.

Plate VI


D.m. Brood (number per sq. ft.)
0
5
10
15
20
25
30
35
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Beneficial Insects (number per sq. ft.)
SCATTER DIAGRAM SHOWING RELATIONSHIP BETWEEN
D.M. BROOD AND BENEFICIAL INSECTS
(All Trees Under Similar Conditions as to
Year of Attack, Site Moisture, Tree Diameter,
Bark Thickness and Density of Attack)

Types of Host Material

In making this study, five different types of host material were recognized, namely (1) fire-scorched trees, (2) slash and cull logs resulting from logging and road construction, (3) physically injured trees such as windfalls and broken-topped trees, (4) diseased trees, mainly those infected with root rot caused by the honey fungus (Armillaria mellea) and (5) uninjured, D.m.-infested trees. Each of these will be discussed in the order named.

Fire-scorched trees were examined during two years of the study on two different areas. The results of these examinations are summarized in table 8.

Table 8 - Insect populations in fire-scorched western white pine compared with general infestation average

Host material	Trees sampled	Average per square foot					
		D.m. brood	Att.	Egg gallery	Parasites	Predators	Robber work
		no.	no.	inches	no.	no.	sq.in.
Fire-scorched	35	0.8	1.3	6.4	.04	0.7	99.8
General average	404	19.5	7.0	77.7	2.8	1.2	28.5

Although this sample represents only two areas during two different years, it is believed that the mountain pine beetle develops very sparse broods in trees which have been actually scorched by fire. Such trees frequently have badly burned roots and in all cases the bark of the lower tree bole becomes very dry, too dry in fact even for secondary bark beetle development. Most of the available bark surface of scorched trees is taken over by other bark-inhabiting species as indicated by the amount of robber work shown in the table.

This discussion deals only with trees actually scorched by fire. Additional data are needed from other burned areas, and consideration should also be given to the attack of adjacent green stands by beetles attracted to the burned area.

Slash and cull logs were examined during two years of the study in four different areas -- two areas representing road slash and two areas of logging slash. In the areas examined by the infestation study crew, all white pine trees felled in the process of road construction were cut into logs and sold. This left only tops and cull logs similar to a logging operation. There is some difference between road slash and logging slash, however, in that road slash is usually well shaded and remains moist for a much longer time than logging slash. Table 9 summarizes the results of these examinations.

Table 9 - Insect populations in road and logging slash compared with general infestation average.

Type of material	Year of attack	Year of examination	Average per square foot				
			D.m. brood	Attacks	Parasites	Predators	Robber work
Road slash	1935	1936	0.7	0.6	0.6	3.2	79.6
	1936	1936	15.1 a/	1.5	0.7	1.2	16.0
	1936	1937	1.2 a/	1.6	0.4	0.9	89.6
Logging slash	1935	1936	0.1	.08	.09	.04	1.5
	1937	1937	2.8	0.2	0.2	0.6	34.3
General average	4 yr.		19.5	7.0	2.8	1.2	28.5

a/ These two examinations were made in the same area during two different seasons.

The data in table 9 indicate that neither road slash nor logging slash in the areas studied produces sufficient mountain pine beetle brood to be of any consideration as one of the causes for outbreaks of this insect. Logging slash, which is usually exposed to bright sunlight and therefore subject to rapid drying, does not even appear to be desirable for attack.

It is to be noted that road slash examined during the year of attack showed a high brood potential, which had decreased materially when a second examination was made the following season. It is possible, however, that under favorable circumstances white pine road slash could produce a rather high D.m. population.

In a report issued 4/ March 11, 1939, an example was given

4/ Bedard, W. D. 1939. An instance of the apparent effect of road construction on mountain pine beetle infestations in western white pine.

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citing the apparent effect of road slash and injured trees on D.m. infestations. Table 10 has been taken from this report to show tree mortality according to location in relation to the road.

Table 10 - Western white pine trees killed according to distance from road

Chains distant from road	Trees killed: Number	Percent	Accumulative total	Accumulative percent
1	135 a/	62.5	135	62.5
5	64	29.6	199	92.1
10	12	5.6	211	97.7
15	5	2.3	216	100.0

a/ 80 of these trees (59.3 percent) were located between the road and the creek.

It is readily apparent that the greatest number of trees were killed within one chain of the road and that 92.1 percent of the mortality occurred within a distance of five chains. This would indicate that under some circumstances there is an apparent attraction of beetles to the stands along newly constructed roads.

Physically injured trees comprise windfalls, broken-topped trees, trees injured by lightning and all those which have suffered some mechanical injury. These represent a class of material in which the trees maintain a full or partial root system for some time and thus provide some moisture to the developing broods. During the course of this study, only windfalls were available for examination so that table 11 gives a comparison between conditions in windfalls and those in uninjured standing trees.

Table 11 - Insect populations in physically injured and uninjured trees

Type of material	Trees sampled	Average per square foot				
		D.m. brood	Attacks	Parasites	Predators	Robber work
	no.	no.	no.	no.	no.	sq.in.
Windfalls	10	25.4	2.1	3.8	4.3	47.7
Uninjured trees	404	19.5	7.0	2.8	1.2	28.5

Table 11 shows that D.m. broods are more abundant in windfalls and similar material than in uninjured trees in spite of the fact that there are a lesser number of attacks as well as a greater amount of robber work and more beneficial insects in windfalls. It is obvious, therefore, that this type of host material is an important factor in infestations of the mountain pine beetle, when such host material is in sufficient quantity to be considered.

Trees weakened by disease comprise mainly those trees infected with root fungi, thought to be mainly one fungus, Armillaria mellea. Owing to the type of damage which is the habit of this fungus, it is sometimes impossible to ascertain the presence of the disease without exposing a large portion of the root system. Even then, it is difficult to make a comparative evaluation of the injury because of the difference in the progressive stages of rot development. However, these infected trees undoubtedly represent a low-resistance class containing a wide variety of conditions, from trees with practically the entire root collar infected to those in which the presence of the fungus can be

found only after digging well out along the lateral roots. Table 12 shows conditions in infected and uninfected trees which were examined in the same area for purposes of comparison.

Table 12 - Comparison of insect populations in infected and uninfected trees

Type of material	Trees sampled	Average per square foot					
		D.m. brood	Attacks	Egg gallery	Parasites	Predators	Robber work
	no.	no.	no.	inches	no.	no.	sq.in.
Infected	21	11.9	10.4	77.6	1.8	0.4	34.6
Uninfected	24	10.8	9.7	72.5	1.9	0.6	36.0

None of the differences apparent in table 12 are significant and it is therefore evident that infection by root fungi has no great influence on D.m. population from the standpoint of brood produced from infected trees. This is further indicated in table 13, in which the 21 trees shown in table 12 are grouped according to the amount of root collar destroyed by the fungus.

Table 13 - Insect populations according to percent of root collar destroyed by armillaria

Percent root collar destroyed	Trees examined	Average per square foot					
		D.m. brood	Attacks	Egg gallery	Parasites	Predators	Robber work
	no.	no.	no.	inches	no.	no.	sq.in.
0	9	10.8	11.6	86.0	1.3	0.3	25.1
1-25	6	15.3	10.7	78.7	2.5	0.5	43.5
26-50	2	10.6	7.9	54.5	1.5	0.1	54.9
51-75	1	12.1	9.8	71.9	4.4	0.3	37.9
76-100	3	7.9	8.5	73.7	0.6	0.2	19.8

It is evident that the degree of infection has no greater influence on D.m. brood than the mere presence of the disease organism. There is, however, one factor to be considered in this connection which has a considerable influence in making determinations of the degree of infection at the time of brood emergence. This is the fact that there is a considerable spread of infection following the death of the tree after beetle attack. Table 14 shows the difference in the number of infected trees determined the same year as attack and one year later.

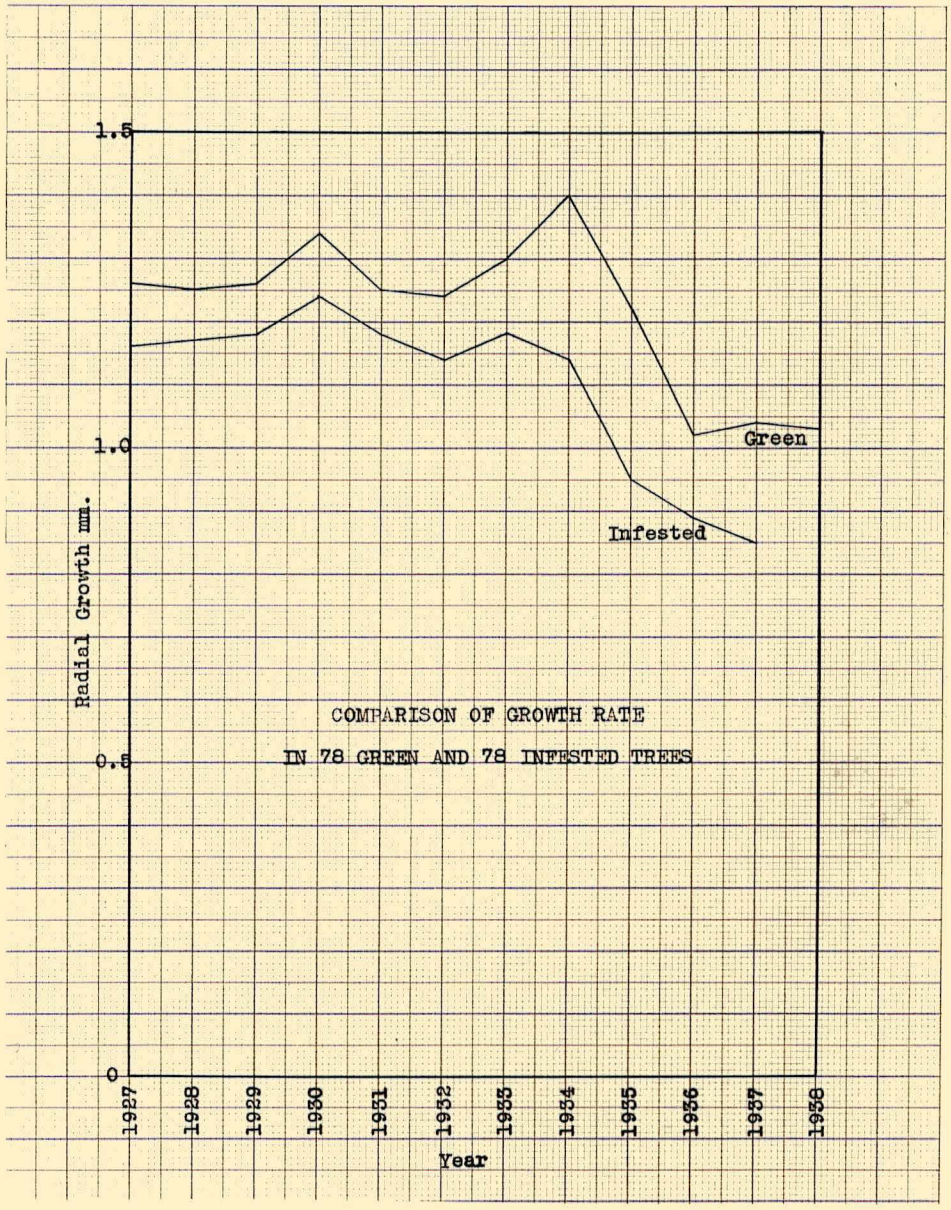
Table 14 - Effect of elapsed time between attack and examination on the frequency of infected trees

Year of D.m. attack	Year of examination	Trees examined	Trees infected	Percent infected	Percent uninfected
		no.	no.		
1938	1938	69	12	17.3	82.7
1938	1939	66	30	45.5	54.5

Although it was not possible to examine the same trees during the two seasons owing to the baring of the roots by examination, this table indicates that there is a rapid spread of the disease organism following attack by the mountain pine beetle. Thus determinations of the degree of infection, made at the time of brood emergence are prone to show a greater infection than actually existed at the time of attack. It is therefore believed that root rots have no important influence on the D.m. infestation in the area studied and probably not on infestations in general.

Tree vigor is probably one of the most difficult factors to determine satisfactorily. Radial growth is often considered a good indicator of vigor and is perhaps as suitable as any available criterion. Plate VII shows the average increment of 78 trees infested with D.m. compared with the average increment of 78 uninfested trees which were immediately adjacent to the infested ones. It is apparent that the infested trees were growing at a slower rate than the green trees, and that they were not as responsive to periods of increased growth and more responsive to depression periods during the past five years. There is so little difference between the two curves, however, that the difference might be due to sampling.

Plate VII


1.5
1.0
0.5
0
Radial Growth mm.
Green
Infested
COMPARISON OF GROWTH RATE
IN 78 GREEN AND 78 INFESTED TREES
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
Year

During the 1939 season, 13 trees were examined which were considered to have been killed by secondary bark-beetles -- an unusual circumstance in western white pine. Two of these trees had been top-killed by Ips vancouveri during the 1938 season and were re-attacked in the basal portion by this same insect species during the 1939 season. Two other trees were examined which had been top-killed by Ips above 80 feet during 1938 and attacked by D.m. below 80 feet during 1939. These 15 trees were all growing on dry sites, but showed no evident reason for death other than the insect attack. The roots were well excavated, but no evidences of root rotting fungi could be found.

There had been practically no radial growth in these trees for the past five years. In fact, an average of 38 rings in the last half inch of wood made an approximate average of only one-third millimeter per year for the past 38 years. Obviously, these trees were in a very low physiological condition, which made them suitable and susceptible to secondary insect attack. Hence, tree vigor undoubtedly has some influence on bark beetle infestations and can conceivably be an important factor, although no data are available for definite conclusions from this study.

PRACTICAL APPLICATION OF RESULTS

Although the main issues of this project have not been completely solved, progress has been made in narrowing the scope of the study. During this elimination process, certain facts have become sufficiently well established to be of immediate use.

One of the findings which will aid in control administration is the apparently small number of beetles which are produced from trees growing on dry sites. These scattered trees growing at higher elevations have always been a source of trouble and expense in control work. They have necessitated spotting and treating on high, brush-covered ridges where working conditions are difficult and infested trees are widely scattered. With the elimination of these trees from the treating program, the cost of control will be materially reduced. In conjunction with the lack of broods in trees on dry sites, the plentiful broods in trees on wet sites indicate where control will be most effective and where the work should be concentrated in the event that control funds will be exhausted prior to completion of the project.

Although of no positive value, the data indicate that the fostering of beneficial insects by leaving trees with a high population of these insects during control will not be an easy task owing to the association of beneficials with the more abundant D.m. broods. Trees under 10 inches d.b.h. show an approximately equal population of beneficials and D.m. but no other similar general situations have been shown by this study. Individual trees sometimes contain a great preponderance of beneficials, but no satisfactory criteria for determining these trees have been established.

A report[5/] submitted April 3, 1939, described a plan for

5/ Bedard, W. D. and Terrell, T. T. 1939. A method for predicting the trend of mountain pine beetle infestations in western white pine.

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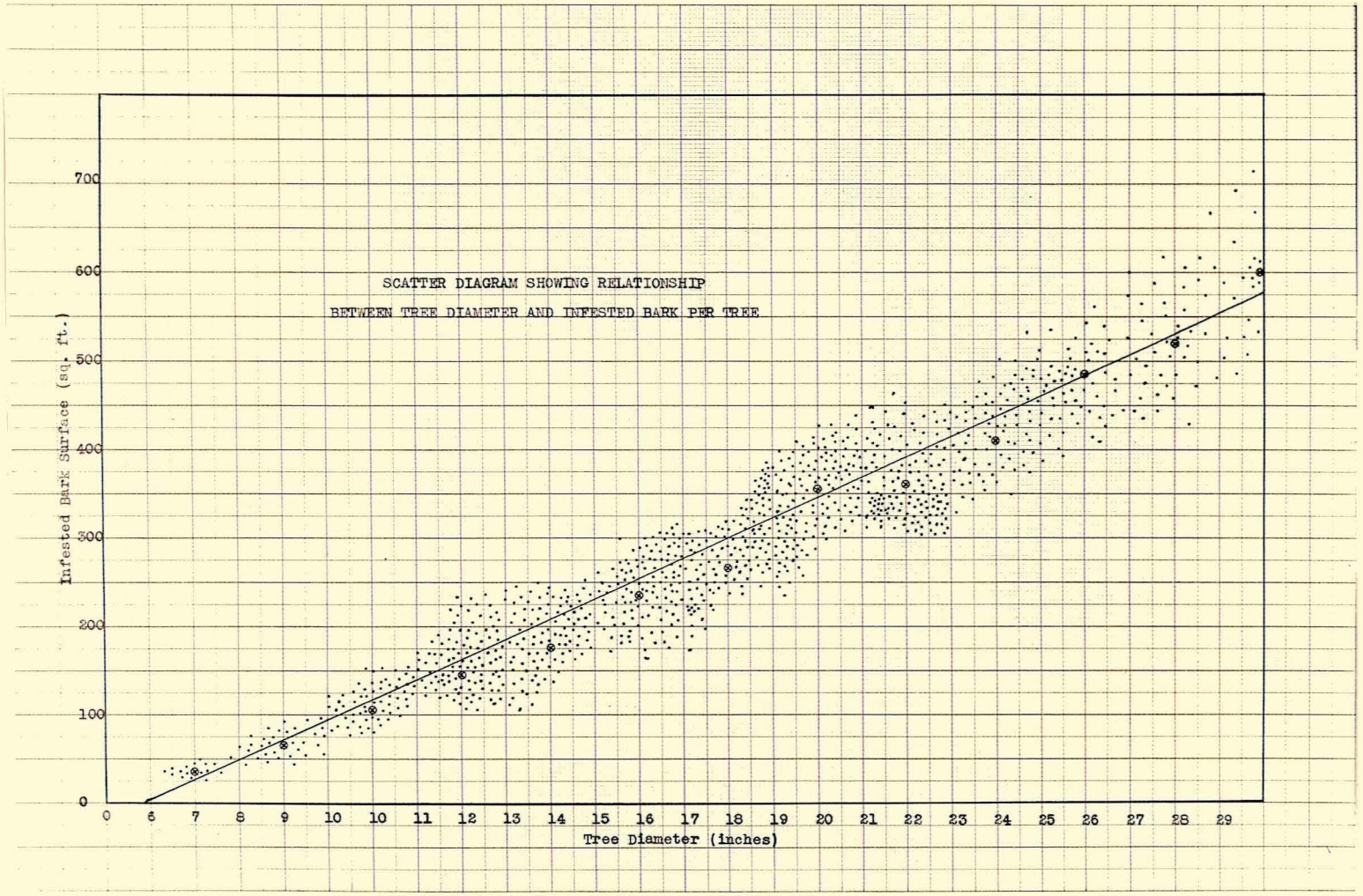
predicting infestation trends based on D.m. population, density of attacks and amount of infested bark surface. It was not feasible to test this method during 1939 by planned experiment, but some checking indicated that it could be used successfully, although there are certain necessary revisions. The most important change is that accurate predictions can not be made on trees containing tiny larvae and eggs. Apparently, an average mortality correction factor can not be applied to these younger brood stages.

Since writing the report, tree diameter was also established as a good indicator of infested bark surface. This is shown in table 15 and plate VIII.

Table 15 - Mean infested bark surface on western white pine according to tree diameter

D.b.h.	Trees examined	Mean infested bark	D.b.h.	Trees examined	Mean infested bark
inches	no.	sq.ft.	inches	no.	no.
6-7	14	32	20-21	56	354
8-9	34	63	22-23	46	360
10-11	63	105	24-25	34	410
12-13	95	148	26-27	22	485
14-15	98	175	28-29	17	522
16-17	93	233	30 +	11	600
18-19	66	262			

Plate VIII


SCATTER DIAGRAM SHOWING RELATIONSHIP
BETWEEN TREE DIAMETER AND INFESTED BARK PER TREE
Infested Bark Surface (sq. ft.)
0
100
200
300
400
500
600
700
0 6 7 8 9 10 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Tree Diameter (inches)

Although there is evidence of a slightly curvilinear relationship, particularly where the tree diameters are larger, the regression equation was computed on the basis of a straight line relationship and was found to be $\bar{x} = 23.353\ y - 143.645$. This places the regression line as shown on the scatter diagram in plate VIII.

The lack of positive information has always made any consideration of slash and cull logs a difficult and uncertain task. Present data indicate that this type of host material is usually not an important consideration, but that a high brood potential in road slash may possibly result in abundant emergence under proper circumstances. Therefore, no general policy regarding this type of host material can be made, but each situation must be considered separately.

These are the facts determined by the infestation study which are immediately applicable to the white pine work. One of the main values of the work, however, is that it has placed a definite value on some of the ideas regarding D.m. infestations in western white pine so that future work can be on a more restricted basis along definite lines indicated by this study.

SUMMARY

Considering the questions which are to be answered by this study, it can be stated that mountain pine beetle infestations in western white pine show significant differences in insect populations from year to year. Although site moisture, the tree diameter--bark thickness relationship, and the density of attack--volume of egg gallery relationship are effective in influencing D.m. broods in

individual trees, they are not of sufficient importance to cause the seasonal differences recorded during the four years of this study. The indications are that the seasonal changes in D.m. population are induced by some factor outside the tree such as climate or some dependent of climate.

In the areas studied, the type of host material had but little effect in causing infestation fluctuations. Under certain circumstances, it is possible that slash or physically injured trees might cause either an increase or decrease in D.m. population, but no such results were apparent in this study.

The second objective of the study concerning the basis upon which mountain pine beetle infestation trends can be predicted has come nearer to solution. A method, previously referred to, for predicting these trends has been developed and if successful will fill an important need in white pine survey work because it has long been realized that a sounder basis than number of infested trees per acre was needed to determine the importance of D.m. infestations.

Respectfully submitted,

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